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STANDARDIZATION OF TECHNOLOGICAL PARAMETERS FOR DRAWING OPTICAL RODS USING EXPERIMENTAL MODELS

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A method for constructing experimental models of drawing optical rods based on experimental data is considered. The models obtained make it possible to identify admissible technological parameter fluctuations in the range selected.

Optical rods drawn from melted glass should have insignificant deviations of cross-sectional geometrical sizes from prescribed values (less than 1%) [1].

Physical models of the drawing process [2] make it possible to formulate the main requirements on drawing sets that are being designed. It is convenient to construct models for operating drawing sets on the basis of an experimental design series [3]. Such models make it possible to adjust a particular process to produce rods of a prescribed quality.

The essence of experimental model construction is as follows. Any process depends on certain controlling factors $\tilde{x}_i$ that have an effect on the process result (response) y. The functional dependence between these factors and the process response can be represented as a polynomial:

$$y = b_0 + \sum_{i<j}^{k} b_{ij}\tilde{x}_i\tilde{x}_j + \sum_{i<j}^{k} b_{ii}\tilde{x}_i^2 + \ldots, \quad (1)$$

where b_0, b_{ij}, $\tilde{x}_i$, and b_{ii} are coefficients whose values are found from experimental results, i.e., controlling factors.

Equation (1) is called the response function or the regression equation. It is an experimental model of the process corresponding to experimental data. This model can be used to solve various problems. It is possible, for instance, to standardize controlling (technological) factors to produce rods of prescribed quality,

It is advisable to carry out experiments in the following order:

– select controlling factors;
– select the response function;
– carry out a multiple-factor experiment, calculate the regression equation coefficients;
– verify significance of the coefficients;
– verify adequacy of the model selected.

Selection of controlling factors depends on a particular technological process. The general requirements imposed on the factors are controllability and single value. Requirements imposed on a set of factors include independence, i.e., possibility of determining the factor at any level regardless of the level of other factors.

Below are the results of experimental studies performed on a standard drawing set consisting of a mechanism feeding intermediate product into a furnace, a furnace, and a drawing mechanism. The feed mechanism is based on screw – nut transmission and the drawing mechanism is based on a chain transmission with two rows of chains, to which carriages with grips are fixed. The glass used to draw glass rods was Kh230. The intermediate product diameter was 22 mm, and the diameter of the rod drawn was 2 mm.

The factors controlling the given process are the glass melt viscosity, drawing force, velocity of feeding the intermediate product to the heating zone, and drawing velocity. Glass melt viscosity depends on temperature in the heating zone. The drawing velocity and the drawing force are dependent factors. The velocity of feeding intermediate product to the heating zone and the drawing velocity are related by means of a certain correlation based on the continuity equation [4]. Consequently, these factors are dependent as well.

Accordingly, it is convenient to use two technological parameters as the controlling factors for the process of drawing rods: drawing velocity and temperature in the heating zone.

Let us introduce the following notations: $\tilde{x}_1$ is the absolute value of drawing velocity; $\tilde{x}_2$ is the absolute value of temperature in the heating zone. Let us introduce normalized variables for experimental design:

$$x_i = \frac{\tilde{x}_i - \tilde{x}_{i\,\mathrm{av}}}{\Delta\tilde{x}_i},$$

where $\tilde{x}_{i\,\mathrm{av}}$ is the average value of the valuable; $\Delta\tilde{x}_i$ is the variation range of the variable; $i = 1, 2$.

The values set in the experiments were: $\tilde{x}_{1\,\mathrm{av}} = 2.5\ \mathrm{m \cdot min^{-1}}$, $\Delta\tilde{x}_1 = 1\ \mathrm{m \cdot min^{-1}}$, $\Delta\tilde{x}_{2\,\mathrm{av}} = 930°\mathrm{C}$,

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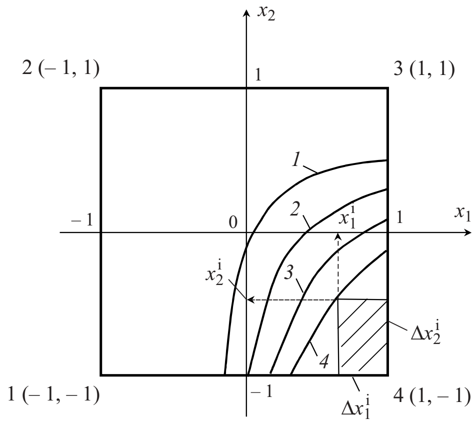

Fig. 1. Ranges of determination of controlling factors.

$\Delta\widetilde{x}_2 = 15°C$. The factors varied at two levels: the upper level (+ 1) and the lower level (– 1).

The response in this process was the deviation Δd of the outer rod diameter from the standard value $\Delta d = y$. To have more reliable results, Δd was measured after drawing rods in stationary conditions. For each drawing regime 12 rods of length 300 mm where randomly chosen and the maximum deviation of diameter was determined for each rod.

Preliminary studies revealed the effect of the controlling factors on the response. Therefore, a model was selected taking into account the mutual effect:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 .$$

A full factorial experiment of type 2^k was carried out (2 is the number of levels of the factors; k si the number of the factors, in our case $k = 2$).

A geometric interpretation of this experiment is shown in Fig. 1. The experiments were carried out at points 1 (factors levels 1 (– 1, – 1), 2 (– 1, 1), 3 (1, 1), and 4 (1, – 1)). The surface of the square represents the range of the experiment.

The regression equation coefficients were calculated and their significance and adequacy of the model chosen were verified according to standard methods [3]. After the experimental data were processed, the following values of the coefficients were obtained (μm): $b_0 = 41$, $b_1 = -25$, $b_2 = 11$, $b_{12} = 33$. Verification established the significance of all factors and the adequacy of the model selected.

The coefficients calculated based on experimental results indicated the extent of effect of the factors. If a coefficient has the sign "plus," the response grows as the value of the factor increases; in the case of the "minus" sign it decreases. Furthermore, the substantial value of the coefficient b_{12} corroborated the results of the preliminary study, i.e., the significant effect of interaction of the factors on the response.

The obtained model

$$y = 41 - 25x_1 + 11x_2 + 33x_1 x_2 \tag{2}$$

makes it possible within the range considered to standardize the controlling factors (technological parameters) taking into account the effect of their interaction.

Equation (2) corresponds to the three-dimensional factor space: the factor values are determined along two axes and the response values are determined along the third axis. This is how the response surface can be represented. However, one can study this surface without passing to a three-dimensional space but restrict oneself to a plane [3]. To do this, the response surface should be intersected by planes parallel to the plane $x_1 0 x_2$ and the intersection lines should be projected on this plane.

In order to represent these projections, it is necessary to set values $y = \Delta d$ in Eq. (2) and construct plots $x_1 = x_1(x_2)$ on the plane $x_1 0 x_2$. Such plots in Fig. 1 are constructed for $\Delta d = 40$, 30, 20, and 10 μm (respective curves *1*, *2*, *3*, and *4*). The plots corroborate the direction toward an optimum combination of controlling fetors predicted by the regression equation coefficients. The same values make it possible to standardize each of the factors taking into account their interaction.

Let us analyze an example. Let the maximum deviation of the rod diameter be $\Delta d = 10$ μm. This deviation correlates with curve *4*. Let us select the initial value of the controlling factor $x_2^i = -0.5$, which correlates with the initial value of controlling factor $x_1^i = 0.61$. The response does not exceed 10 μm if the factor variation ranges are Δx_1^i and Δx_2^i (Fig. 1), i.e., the factor variation limits will be

$$0.61 \le x_1 \le 1; \quad -1 \le x_2 \le -0.5.$$

Or, passing to natural values, we obtain

$$3.11 \text{ m/min}^{-1} \le \widetilde{x}_1 \le 3.50 \text{ m/min}^{-1};$$

$$915°C \le \widetilde{x}_2 \le 922.5°C.$$

The range of admissible factor variations in Fig. 1 is indicated by dashed lines.

Thus, experimental models of the process makes it possible to validate the selection of admissible ranges for variation of technological parameters taking into account their mutual effect.

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